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(54) Modified lipopolysaccharides

(57) Modified lipopolysaccharides, particularly de-3-O-acylated monophosphoryl lipid A and de-3-O-acylated diphosphoryl lipid A, are provided by an alkaline hydrolysis under controlled conditions which removes only the β -hydroxymyristic acyl residue that is ester-linked to the reducing-end glucosamine at position 3. The modified products are less endotoxic and maintain their antigenic and immuno-stimulating properties.

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MODIFIED LIPOPOLYSACCHARIDES AND PROCESS OF PREPARATION

FIELD OF THE INVENTION

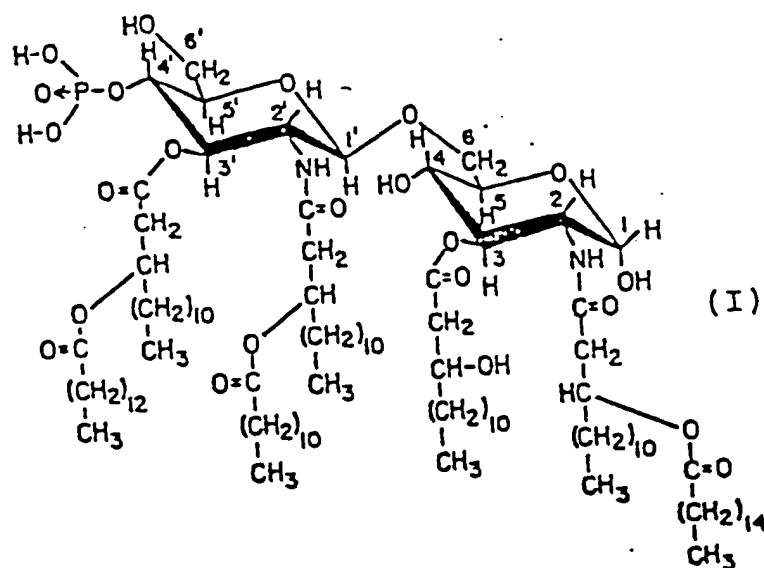
This invention relates in general to certain modified forms of lipopolysaccharide and lipid A. In one aspect, this invention is directed to a process for the structural modification of certain lipopolysaccharides to render them less endotoxic without adversely affecting their antigenic or immuno-stimulating properties.

BACKGROUND OF THE INVENTION

Prior to the present invention, it had long been recognized that enterobacterial lipopolysaccharides (LPS) was a highly potent stimulator of the immune system. A variety of responses, both beneficial and harmful, can be elicited by sub-microgram amounts of this substance. The fact that some of these responses are harmful, and can in fact be fatal, has to date precluded clinical use of LPS per se. It is now also well-appreciated that the endotoxic activities associated with bacterial lipopolysaccharides (LPS) reside in the lipid A component of LPS.

Accordingly, much effort has been expended towards attenuating the toxic attributes of lipid A and LPS without diminishing their beneficial immunostimulatory activities. Notable among these efforts was that of Edgar Ribi and his associates, which resulted in the production of a derivative of lipid A referred to originally as refined detoxified endotoxin (RDE) but more recently as monophosphoryl lipid A

(MPL). MPL is produced by refluxing LPS (or lipid A) obtained from heptoseless mutants of gram negative bacteria (e.g. Salmonella sp.) in mineral acid solutions of moderate strength (e.g., 0.1 N HCl) for a period of approximately 30 minutes. This treatment results in the loss of the phosphate moiety at position 1 of the reducing-end glucosamine. Coincidentally, the core carbohydrate is removed from the 6' position of the non-reducing glucosamine during this treatment. The result is the monophosphoryl derivative of lipid A, MPL. The structure of MPL is shown below:



MPL exhibits considerably attenuated levels of the endotoxic activities normally associated with lipid A and LPS, such as pyrogenicity, local Shwarzman reactivity, and toxicity in the chick embryo 50% lethal dose assay (CELD₅₀). It retains the ability of lipid A and LPS, however, to, among other things, act as an adjuvant, and stimulate non-specific resistance to infectious challenge.

The difficulty with this method of detoxifying LPS and lipid A is that it invariably results in the loss of the core moiety attached to position 6' of the non-reducing glucosamine. This is significant since the core region is highly conserved among LPS's obtained from different genera of Enterobacteriaceae; immunity against the core region is therefore protective against a wide variety of gram negative bacterial challenges. This was demonstrated by the work of Ziegler et al. (New Eng. J. Med. 307, 1225: 1982), for example.

Considerable benefits would accrue from being able to immunize individuals against enterobacterial LPS, as evidenced by the fact that approximately 90,000 deaths occur annually from gram negative sepsis and associated endotoxemia. At the present time, however, it is only possible to immunize with fully toxic LPS, since detoxification by acid hydrolysis results in loss of the core region.

Alkaline hydrolysis has also been used in the past to detoxify LPS, but the conditions which have generally been used result in complete saponification of the lipid A moiety. This, of course, not only reduces the endotoxicity of the starting LPS, but also eliminates the other, more beneficial, activities as well. Furthermore, such treatment also reduces the immunogenicity of LPS, since it is essentially converted by this treatment into a polysaccharide antigen with no amphipathic character. In general, however, none of the early references teaches that removal of one particular fatty acid from lipid A would render it non-toxic, while not affecting its immunostimulating activities.

Accordingly, one or more of the following objects will be achieved by the practice of this invention. It is an object of this invention to provide modified lipopolysaccharides and, in particular, modified lipid A. Another object of this invention is to provide a modified lipid A which retains the core moiety attached to the 6' positions of non-reducing glucosamine. A further object of the present invention is to provide a modified lipid A which retains the core moiety and accordingly, protection against a wide variety of gram negative challenges. A still further object of the present invention is to provide a process for the preparation of the modified lipid A which renders it less endotoxic without adversely affecting their antigenic or immunostimulating properties. Another object is to provide pharmaceutical compositions containing the modified lipopolysaccharides and a method for their use. These and other objects will readily become apparent to those skilled in the art in light of the teachings herein set forth.

SUMMARY OF THE INVENTION

In its broad aspect, the present invention is directed to certain modified forms of lipopolysaccharide and lipid A, and to a process for their preparation. The invention also encompasses pharmaceutical compositions containing the modified lipopolysaccharides and their use in the treatment of various conditions in warm blooded animals.

The modified lipopolysaccharides and lipid A of this invention are those which have been subjected to a mild alkaline hydrolysis under conditions as hereinafter defined that result in the loss of a single fatty acid from position

3 of the lipid A backbone.

DETAILED DESCRIPTION OF THE INVENTION

There is a considerable body of literature which pertains to the effect of alkaline treatment on the biological activities of LPS and lipid A. Most of these references teach the use of conditions that are sufficient to completely deacylate lipid A. As stated earlier, such treatment destroys essentially all biological activity of lipid A and LPS, except for antigenicity. The early paper by Neter et al. (Neter E., Westpahl O., Luderitz O., Gorzynski E. A. and Eichenberger E., "Studies of enterobacterial lipopolysaccharides". Effects of heat and chemicals on erythrocyte modifying, antigenic, toxic, and pyrogenic properties", J. Immunol. 76, 377: 1956), can be regarded as representative of the state of the art which teach the use of alkaline conditions sufficient to destroy all biological activities of LPS.

Several other observations have been noted in the scientific literature concerning alkaline hydrolysis of lipid A and LPS. For example, Niwa et al. (J. Bacteriol. 97, 1069: 1969;) observed that treatment of LPS with mildly alkaline conditions caused a rapid loss of endotoxic activity and a much slower loss of fatty acids. This observation led them to conclude that the fatty acid-containing portion of LPS, lipid A, was not responsible for the endotoxic activity of LPS, since it was evidently destroyed at a slower rate than the endotoxic activity was lost. The authors conjectured that the only way that their observations might be consistent with lipid A being the endotoxic principle was if there existed a fatty acid in lipid A that was both highly

alkaline-labile and necessary for endotoxic activity. The authors did not consider this to be a likely explanation. At the time, Niwa et al. favored an explanation for their results based on the influence of mild alkaline treatment on the conformation of endotoxin aggregates.

In a paper by Rietschel et al. (Eur. J. Biochem. 28, 166; 1973), it was noted that β -hydroxymyristic acid is rapidly released from lipid A upon mild alkali treatment (0.25 N NaOH, 56° C). The reason for the rapid loss of β -hydroxymyristic acid was not given, nor was it known from which position this fatty acid was cleaved. Also, no mention was made of the relationship of this rapid loss of β -hydroxymyristic acid to the loss of endotoxicity upon mild alkaline treatment which was observed by Niwa et al. and others.

In a paper by Goodman and Sultz (Infect. Immunity 17, 205; 1977;) the authors noted that mild alkaline hydrolysis of LPS reduced its toxicity while actually enhancing its mitogenicity. They chemically characterized the hydrolyzed product with respect to nitrogen, glucosamine, KDO, and fatty acid content. Significantly, they found that the fatty acid content was relatively unchanged by the alkaline treatment. This led Goodman and Sultz to conclude that the effect of the mild alkaline treatment was mediated by changes in the aggregational properties of the hydrolyzed LPS. In this regard, they were adopting the view of Niwa et al. On p. 212 of their paper, Goodman and Sultz state that "...we have reduced the toxicity of the [LPS] by about 100-fold without significantly changing the lipid moiety." This confirms that they did not understand what they had done to achieve the observed reduction in toxicity without reducing mitogenicity. No mention was made of the possibility of a critical fatty

acid that is alkaline-labile.

The sensitivity of ester-linked β -hydroxymyristic fatty acid residues present in lipid A to alkaline hydrolysis was noted in a 1982 publication (N. Oureshi, D. Takayama, and E. Ribí, J. Biol. Chem. 257, 11808: 1982). Similar observations were made with respect to a monosaccharide precursor of lipid A in a 1983 publication (Takayama, et al., J. Biol. Chem. 258, 14245: 1983). Both of these references teach that ester-linked β -hydroxymyristic fatty acid residues present in lipid A or related compounds are easily removed by mild alkaline treatment. The effect of this structural modification on the biological activity of lipid A was not recognized in this or any subsequent references.

The treatment of LPS with mild alkali was discussed in two papers by Amano, et al. (D. Amano, E. Ribí, and J. L. Cantrell, J. Biochem 93, 1391: 1983, and K. Amano, E. Ribí, and J. L. Cantrell, BBRC 106, 677: 1982). The authors reported that mild alkali treatment results in the loss of O-ester linked fatty acids. They did not mention that the only fatty acid removed by this treatment is the β -hydroxymyristic at position 3. Also, contrary to the results disclosed in the present invention, they reported that mild alkali treatment did not reduce the endotoxicity of the parent LPS.

A study of the structural consequences of treating LPS with mild alkali was reported in a paper by Rosner, et al. (M. R. Rosner, J-y Tang, I. Barzilay, and H. G. Khorana, J. Biol. Chem. 254, 5906: 1979). The authors reported that LPS which was treated with 1 N NaOH at room temperature for approximately 17 hrs was exhaustively de-O-acylated. This is clearly different from the present invention, which discloses

conditions sufficient to remove only the β -hydroxymyristic from position 3. Furthermore, the authors subjected LPS to this mild alkali treatment solely for the purpose of elucidating LPS's structure. No mention is made in this article of the effect of mild alkali treatment on the biological activities of LPS.

The use of mild alkali treatment to lower the toxicity of lipid A was disclosed in U.S. Patent 4,029,762. this patent discloses the use of lipid A and alkali-treated lipid A as antigens for stimulating immunity against gram-negative enterobacteriaceae. It was not disclosed in this patent that lipid A, which lacked a β -hydroxymyristic acid at position 3, is less endotoxic but is still mitogenic. ✓

In a 1987 review by Rietschel et al. (in "Detection of Bacterial Endotoxins with the Limulus Amebocyte Lysate Test", Alan R. Liss, Inc., 1987, p. 25-53;), mention is made of the fact that synthetic monosaccharides corresponding to the reducing end of lipid A are inactive if the β -hydroxymyristic acid residue at position 3 is removed. The authors, however, did not conjecture as to whether the same observation would be made with lipid A, and no work was cited pertaining to this question. It does not appear then that it was suspected that removal of the β -hydroxymyristic acid from position 3 of lipid A and LPS would result in reduced endotoxicity without affecting activities such as mitogenicity. ✓

Accordingly, prior to the present invention, and in view of the reported research efforts of Edgar Ribi and his colleagues, in preparing and evaluating monophosphoryl lipid A, it was generally recognized that detoxification of lipopolysaccharide was best accomplished by an acid hydrolysis followed by a chromatographic separation of MPL if a product

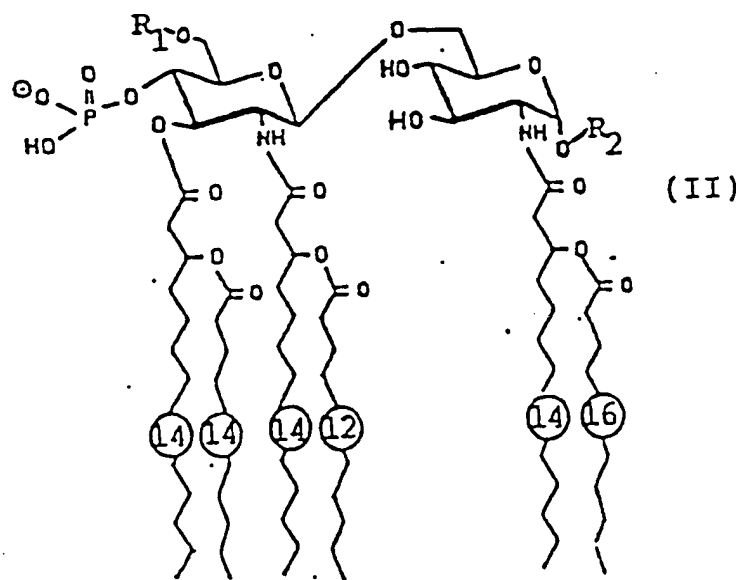
having enhanced immuno-stimulating properties was desired.. It was not readily apparent that the endotoxicity of lipid A could be attenuated by removal of only the fatty acid at position 3 or that removal of the position 3 fatty acid from lipopolysaccharide would reduce endotoxicity and yet allow other desirable substituents to remain in the molecule.

Thus, in contrast to the prior art references which may disclose, in general, the alkaline treatment of lipopolysaccharides, none of these references clearly recognizes the unexpected and surprising results obtained by employing conditions for removal of only the β -hydroxymyristic acyl residue from lipopolysaccharides and thereafter separating and recovering the deacylated product in a relatively pure form.

Lipid A deacylated in accordance with the method of the present invention was found to be non-toxic in the CELD₅₀ assay (CELD₅₀ >10 μ g), in spite of the fact that it still contained 1) a diglucosamine backbone, 2) two phosphoryl groups, 3) at least two 3-acyloxyacyl residues, and 4) up to a total of 6 fatty acids. Taken together, these results indicate that the total number of fatty acids present in lipid A is not a sufficient condition for the manifestation of endotoxic activity, but that the pattern of fatty acid substitution is also a critical determinant.

While not wishing to be bound by any theory regarding the reasons why the compound(s), although less endotoxic, are still able to exert a strong immunostimulating effect, it is believed that the specific structural modification that is responsible for this reduction in the endotoxicity of lipid A and LPS involves removing of the β -hydroxymyristic acyl residue that is ester-linked to the reducing-end glucosamine

at position 3 under conditions which do not adversely affect other groups in the lipopolysaccharides. Monophosphoryl lipid A (MPL), diphosphoryl lipid A (DPL) and LPS can all be de-3-O-acylated in this way. The structures of these novel materials are shown below in formula II wherein the figures in the circles indicates the number of carbon atoms in the chain.



| Compound | R1 | R2 |
|----------|--------------------|--------------------------------|
| δ3-MPL | H | H |
| δ3-DPL | H | PO ₃ H ⁻ |
| δ3-LPS | Core (+ O-antigen) | PO ₃ H ⁻ |

Various forms of de-3-O-acylated materials are encompassed by this invention. The lipid A backbone that is shown corresponds to the product that is obtained by de-3-O-acylation of heptaacyl lipid A from S. minnesota R595. Other fatty acid substitution patterns are encompassed by this disclosure; the essential feature is that the material be de-3-O-acylated.

Thus, the embodiment of this invention is directed to the composition of MPL, DPL and LPS in which the position 3 of the reducing end glucosamine is de-0-acylated. These compounds as indicated above are referred to as d3-MPL, d3-DPL, and d3-LPS, respectively.

Also as indicated above, the modified lipopolysaccharides of the present invention are prepared by subjecting the compounds to alkaline hydrolysis under conditions that result in the loss of but a single fatty acid from position 3 of the lipid A backbone.

The β -hydroxymyristic at position 3 is unusually labile in alkaline media. It requires only very mild alkaline treatment to completely de-3-0-acylate lipid A and LPS. The other ester linkages in lipid A and LPS require somewhat stronger conditions before hydrolysis will occur, so that it is possible to selectively deacylate these materials at position 3 without significantly affecting the rest of the molecule. The reason for the unusual sensitivity to alkaline media of the ester-linked β -hydroxymyristic at position 3 is not known at this time.

Although alkaline hydrolysis procedures are known, it is important to choose conditions that do not cause further hydrolysis beyond the ester linkage to the β -hydroxymyristic at position 3.

In general, the hydrolysis can be carried out in aqueous or organic media. In the latter case, solvents include methanol (alcohols), dimethyl sulfoxide (DMSO), dimethylformamide (DMF), chloroform, dichloromethane, and the like as well as mixtures thereof. Combinations of water and one or more of these organic solvents also can be employed.

The alkaline base can be chosen from among various hydroxides, carbonates, phosphates and amines. Illustrative bases include the inorganic bases such as sodium hydroxide, potassium hydroxide, sodium carbonate, potassium carbonate, sodium bicarbonate, potassium bicarbonate, and the like, and organic bases such alkyl amines and include, but are not limited to, diethylamine, triethylamine and the like.

In aqueous media, the pH is typically between approximately 10 and 14 with a pH of about 12 to about 13.5 being the preferred range. The hydrolysis reaction is typically carried out at a temperature of from about 20 to about 80°C, preferably about 50 to about 60°C for a period of about 10 to about 30 min. For example, the hydrolysis can be conducted in 3% triethylamine in water at room temperature (22-25°C) for a period of 48 hrs. The only requirement in the choice of temperature and time of hydrolysis is that de-O-acylation occurs to remove only the β -hydroxymyristic at position 3.

In practice, it has been found that a particularly desirable hydrolysis method involves dissolving lipid A or monophosphoryl lipid A in chloroform:methanol 2:1 (v/v), saturating this solution with an aqueous buffer consisting of 0.5M Na_2CO_3 at pH 10.5, and then to flash evaporate the solvent at 45-50°C under a vacuum from an aspirator (approximately 100 mm Hg). The resulting material is selectively deacylated at position 3. This process can also be carried out with any of the inorganic bases listed above. The addition of a phase transfer catalyst, such as tetrabutyl ammonium bromide, to the organic solution prior to saturating with the aqueous buffer may be desirable in some cases.

In preparing the modified lipopolysaccharides of this invention, it is deemed highly important that LPS can be

deacylated at position 3 without causing any changes in the O-antigen or core regions or in the structure of the lipid A component except for loss of the labile fatty acyl residue. There are several implications of this result with respect to possible uses of the de-3-0-acylated compounds. For example, vaccines against gram negative bacteria and/or endotoxin can be generated using LPS that has been treated in the manner of this disclosure which results in a preparation with low endotoxicity but with the same antigenic attributes as the parent material, and which is able to act as its own adjuvant. Such preparations may be able to promote a strong specific immune response without the toxic effects generally associated with LPS-based vaccines.

Another implication is that lipid A that has been detoxified by de-3-0-acylation, since it still contains both phosphates, may have greater immunostimulatory activities than lipid A that has been detoxified by the prior art method involving acid hydrolysis to remove the reducing end phosphate. For example, acid hydrolyzed LPS, which is referred to as monophosphoryl lipid A (MPL), is less mitogenic with respect to B-lymphocyte proliferation than is d3-LPS. Thus, de-3-0-acylated lipid A and LPS may be more potent immunostimulators than is MPL. Furthermore, because of structural differences between MPL and de-3-0-acylated lipid A and LPS, the latter compounds may exhibit a different spectrum of beneficial biological activities than does MPL.

It is therefore viewed as a significant advance to be able to reduce the endotoxicity of LPS without eliminating its antigenic attributes or its immunostimulating activity. LPS subjected to mild alkaline hydrolysis can be used to immunize warm blooded animals including humans, thus

conferring protection against gram-negative septicemia and associated endotoxemia.

A further advantage of d3-LPS and d3-DPL relative to MPL is that these materials, since they possess both of the phosphate groups present in lipid A, may exhibit enhanced activities relative to MPL, which is lacking the phosphate moiety at the 1 position. This has already been found with respect to mitogenicity; d3-LPS is as mitogenic as the parent LPS, whereas MPL is only about half as mitogenic.

Finally, the conditions used to effect the mild alkaline hydrolysis disclosed herein are, in some cases, easier to attain than those of the prior art methods for detoxifying LPS or lipid A. For example, as mentioned above, lipid A can be detoxified by dissolving it in a solution chloroform:methanol 2:1 (v/v), saturating this solution with an aqueous buffer consisting of 0.5 M Na_2CO_3 at pH 10.5, and then evaporating the solvent at 45-50°C. This method is also effective in removing the residual endotoxicity which is usually found in crude preparations of MPL, and which is typically removed by chromatographic purification. Thus, mild alkaline hydrolysis can obviate the need for the costly and time-consuming chromatography steps which are generally required in order to fully-detoxify preparations of MPL.

The lipopolysaccharide which is free of the β -hydroxymyristic acid residue, can be covered from the reaction medium in relatively pure form.

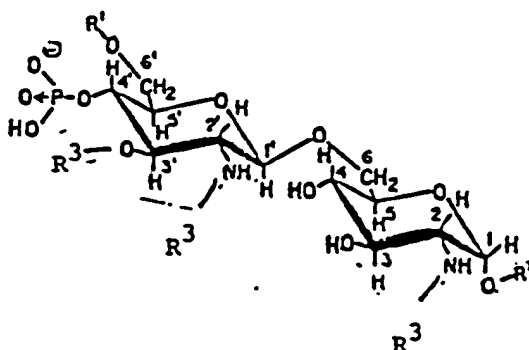
Although the present invention is particularly useful for de-3-O-acylating MPL, it is applicable to lipopolysaccharides in general. Lipopolysaccharides represent a biologically active class of substances and chemically are made up of a polysaccharide portion, the

O-specific chains (O-antigen) and the core, and a covalently bound lipid, lipid A. Lipid A represents the endotoxically active region of lipopolysaccharides, while the polar polysaccharide part serves as a solubilizing carrier. Lipid A of *Salmonella* consists of a backbone of β -1,6-linked D-glucosamine disaccharide units which are substituted at positions 1 and 4' by phosphate-residues and at position 6' by the core polysaccharide. The other hydroxyl and the amino groups of the backbone are acylated by long-chain fatty acids, of which lauric, myristic, palmitic and 3-hydroxymyristic acid predominate.

The term "monophosphoryl lipid A", "(MPL)" or "(MLA)" as used herein is meant to designate the monophosphoryl lipid A of structure I and is obtained from lipopolysaccharides such as *Salmonella minnesota* R 595, *Escherichia coli*, and the like. MLA is reported by N. Qureshi et al. *Journal of Biological Chemistry*, Vol 260. No. 9. pages 5271-5278 (1985).

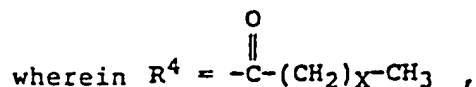
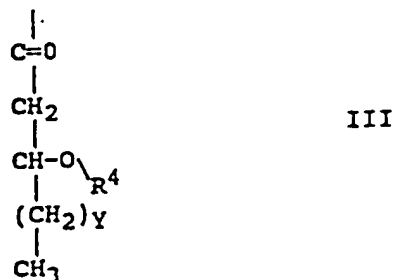
Accordingly, the lipopolysaccharide compounds of this invention after de-3-O-acylation, can also be represented by the formula.

A lipopolysaccharide compound of the formula



wherein R^1 is selected from the group consisting of hydrogen and the core component of enterobacterial lipopolysaccharide, with or without the O-antigen present, R^2 is selected from

the groups H and PO_3H_2 , and a R^3 is selected from the group consisting of H, β -hydroxymyristoyl, and a 3-acyloxyacyl residue having the formula:



and wherein X and Y have a value of from 0 up to about 20 and preferably 10, 12 or 14.

The compounds prepared by the present invention are therefore substantially pure compounds and not mixtures of partially de-O-acylated compounds.

All of the uses that are disclosed in the literature for MPL can be entertained with respect to d3-MPL and, especially, d3-DPL. These include a) use as an adjuvant, b) protection against radiation, c) protection against gram negative septicemia and associated endotoxemia, d) protection against non-specific infectious challenges, and e) treatment of neoplastic disease. The de-3-O-acylated materials are used in the same way as MPL in all of these applications, i.e., at the same doses, in the same combinations.

Additionally, d3-LPS can be used as a vaccine against gram-negative infections. In this regard, the material is prepared from LPS obtained from either a wild-type strain of a gram negative organism or else from a strain that has a

partially-complete (and therefore antigenically cross-reactive) core region (e.g. E. coli J5). Such d3-LPS can be administered either in saline, in a lipid emulsion system, or in an oil-in-water emulsion (1-2% squalane or squalene, 0.2% Tween 80). In the latter case, other bacterially-derived immunostimulants (CWS, TDM) can be used in combination with d3-LPS. The amount of d3-LPS per dose is between about 10 and about 1000 µg, and preferably between about 20 and about 200 µg. CWS and TDM, if used, and at similar levels per dose.

The following examples are illustrative of the present invention.

EXAMPLE 1. Removal of the 8 - Hydroxymyristic Acid at Position 3 of Escherichia coli D31M4 MPL by Treatment with Organic Alkaline Media.

580 mg of crude E. coli D31M4 MPL was dissolved in 250 mls of chloroform:methanol 2:1 (v/v). This solution was transferred to a 1 liter separatory funnel, where it was washed with 100 mls 0.5 M Na₂CO₃, pH 10.5. The organic phase was removed, and the solvent was stripped off by flash evaporation using a water aspirator and a bath temperature of 45°C. The resulting residue contained 615.9 mg of de-3-0-acylated MPL (d3-MPL), as judged by thin layer chromatography (Silica gel 60, chloroform:methanol:water:ammonium hydroxide 50:31:6:2 (v/v); plates visualized by spraying with ammonium molybdate in ethanol (10% w/v) and charring).

EXAMPLE 2: The 50% Lethal Dose in Chick Embryos (CELD₅₀ of Crude MPL Before and After De-3-0-Acylation.

MPL and d3-MPL (prepared in Example 1, above) were dispersed in sterile water containing 0.2% triethylamine (TEA; v/v) to a concentration of 2.0 mg/ml. An ultrasonic bath and mild warming (45 - 50°C) promoted solubilization. To these solutions were added equal volumes of 1.8% NaCl (w/v), giving final solutions that contained 1.0 µg/ml MPL or d3-MPL, 0.9% NaCl (w/v), and 0.1% TEA (v/v). The toxicity of these solutions in 11 day-old chick embryos was then assessed by the method of Milner and Finklestein (J. Infect. Diseases 116, 259: 1966). The chick embryo 50% lethal doses (CELD₅₀) were calculated by the method of Reed and Muench (Am. J. Hyg. 27, 493: 1938). The CELD₅₀ of the crude MPL used in Example 1 was found to be less than 1 µg. On the other hand, the d3-MPL did not kill any chick embryos even at 20 µg, the highest dilution tested.

EXAMPLE 3: De-3-0-Acylation of Salmonella minnesota R595 LPS by Treatment with Aqueous TEA.

Into a 4 ml screw-top vial was placed 10.1 mg S. minnesota R595 LPS. 2.0 ml sterile water was added to the vial, which was then capped and sonicated for 3 min. at room temperature. The vial was then placed in a boiling water bath. After 5 min. the vial was removed from the bath and 67 µl TEA was added to the solution, with stirring. The vial was capped and allowed to stand at room temperature for 43 hr. At this time, the extent of de-3-0-acylation was assessed by first subjecting a small portion of the reaction

solution to acid hydrolysis, in order to convert all of the LPS to MPL. This was accomplished by adding 0.3 ml of 0.47 N HCl to a 0.2 ml aliquot of the reaction solution, then placing the acidified solution into an oil bath (130°C) for 10 min. The solution was stirred during this time. The solution was then cooled in an ice-water bath, and the MPL was extracted using 1.0 ml chloroform:methanol 2:1 (CM 2:1; v/v). A control solution was prepared by dispersing 1.00 mg LPS in 0.2 ml water plus 6.7 ul TEA, adding 0.3 ml of 0.47 N HCl, incubating in a 130°C oil bath for 10 min., cooling and extracting with CM 2:1. The alkaline-hydrolyzed material and the control were then analyzed by TLC, as described in Example 1. TLC revealed that almost all of the MPL from the TEA-treated LPS was de-3-O-acylated, which indicated that the TEA treatment had resulted in the production of d3-LPS. The control sample, which had not been exposed TEA for the extended period, appeared identical to MPL from untreated LPS. The TEA hydrolysis reaction was therefore judged to be complete. The remaining reaction mixture was dialyzed against distilled water (6,000 - 8,000 MWt cutoff) and lyophilized, yielding 8.45 mg d3-LPS.

EXAMPLE 4: Biological Activity of d3-LPS

The endotoxicity of the d3-LPS prepared in example 3 was compared with that of the starting LPS using the CELD₅₀ assay, as described in Example 2. The activities of LPS and d3-LPS were also evaluated in a lymphocyte proliferation assay, based on uptake of ³H-thymidine by murine spleen cells following exposure to these materials. The results from these assays are shown in Table 1. They indicate that d3-LPS, while much less endotoxic than the parent LPS, is

still a potent mitogen.

TABLE 1

The effect of de-3-0-acylation on the biological activities of S. minnesota R595 LPS.

| <u>Sample</u> | <u>CELD₅₀</u> ^a | <u>Mitogenicity</u> ^b | |
|---------------|---------------------------------------|----------------------------------|-----------------------------|
| | | <u>C3H/FeJ</u> ^c | <u>CeH/HeJ</u> ^c |
| LPS | 0.03ug | 33.9 | 4.4 |
| d3-LPS | 1.4ug | 30.0 | 5.2 |

Notes:

- ^a The dose necessary to cause 50% mortality in 11 day old chick embryos.
- ^b Lymphocyte proliferation assay, based on uptake of ³H-thymidine by murine spleen cells. The numbers represent the ratio of ³H counts in stimulated cells to counts in unstimulated cells.
- ^c C3H/FeJ mice are LPS-responsive; C3H/HeJ mice are LPS-unresponsive.

EXAMPLE 5: The Rate of De-3-0-Acylation and Detoxification of S. minnesota R595 Diphosphoryl Lipid A (DPL) in Organic Alkaline Media.

Into each of 4 100 x 16 mm test tubes was placed 2.0 mg S. minnesota R595 DPL. To each tube was added 5 ml CM 2:1 and 2 ml 0.5 M Na₂CO₃ pH 10.5. The test tubes were vortexed, centrifuged for 5 min at 3000 g, and the organic layers were withdrawn and transferred to clean test tubes. These solutions were then incubated for varying periods of time at 51-52°C (0, 2, 5, and 10 min). The reactions were quenched at the indicated times by placing the tubes in an ice-water bath and adding ice chips to the solutions. After about 30 sec, 2.0 ml of 0.1 N HCl was added to each test tube, and the

tubes were vortexed and centrifuged. The organic layers were transferred to clean test tubes and washed with distilled water (plus ice chips). Finally, the organic layers were evaporated under a stream of nitrogen. A 0.4 mg portion of each residue was subjected to acid hydrolysis by the method described in Example 3, in order to convert the residues to the corresponding MPLs. The MPLs were then analyzed by TLC as described in Example 1, and the endotoxicities of the corresponding DPL residues from each time point were measured with the CELD₅₀ assay, as described in Example 2. The results are summarized in Table II.

TABLE II

The Rate of De-3-0-Acylation and Detoxification of S. minnesota R595 Diphosphoryl Lipid A (DPL) in Organic Alkaline Media.

| <u>Incubation Time^a</u> | <u>Extent of De-3-0-Acylation^b</u> | <u>CELD₅₀^c</u> |
|------------------------------------|---|--------------------------------------|
| 0 min | None | 0.085 µg |
| 2 | Half | NT |
| 5 | Almost complete | 1.78 |
| 10 | Complete | 10 µg |

Notes:

- ^a The time each tube was incubated at 51-52°C.
- ^b As judged visually from the TLC appearance of the MPL corresponding to the DPL at each time point.
- ^c The dose necessary to cause 50% mortality in 11 day-old chick embryos.

Although the invention has been illustrated by the preceding examples, it is not to be construed as being limited to the materials employed therein but rather, the invention relates to the generic area as herein before disclosed. Various modifications and embodiments thereof can be made without departing from the spirit or scope thereof.

CLAIMS

1. A method for modifying a lipopolysaccharide to selectively remove only the β -hydroxymyristic acyl residue that is ester-linked to the reducing-end glucosamine at position 3 of said lipopolysaccharide, which comprises subjecting said lipopolysaccharide to alkaline hydrolysis sufficient only to remove β -hydroxymyristic acid from position 3 without removal of other fatty acids from the lipopolysaccharide molecule and recovering said lipopolysaccharide free of said residue.
2. The method of claim 1 wherein said lipopolysaccharide is enterobacterial lipopolysaccharide.
3. The method of claim 1 wherein said lipopolysaccharide is monophosphoryl lipid A.
4. The method of claim 1 wherein said lipopolysaccharide is diphosphoryl lipid A.
5. The method of any of claims 1-4 wherein the hydrolysis is conducted in the presence of sodium carbonate.
6. The method of any of claims 1-4 wherein the hydrolysis is conducted in the presence of triethylamine.
7. The method of any of claims 1-4 wherein the hydrolysis is conducted in an organic medium.
8. The method of claim 1 wherein said hydrolysis is conducted in an aqueous medium.
9. The method of claim 1 wherein said hydrolysis is conducted at a pH of from about 10 to about 14 and at a temperature of from about 20 to about 80° C.
10. A method for removing from lipid A or monophosphoryl lipid A, only the β -hydroxymyristic acyl residue that is ester-linked to the reducing-end glucosamine

at position 3 of said lipid A, which method comprises the steps of:

- (a) dissolving said lipid A in an inert organic solvent;
- (b) saturating said solvent with an aqueous buffer comprised of an alkaline compound, at a pH of from about 10 to about 13;
- (c) flash evaporating said solvent under a vacuum at a temperature of between about 40°C and about 60°C; and
- (d) recovering said lipid A.

11. The method of Claim 10 wherein the lipid A is monophosphoryl lipid A.

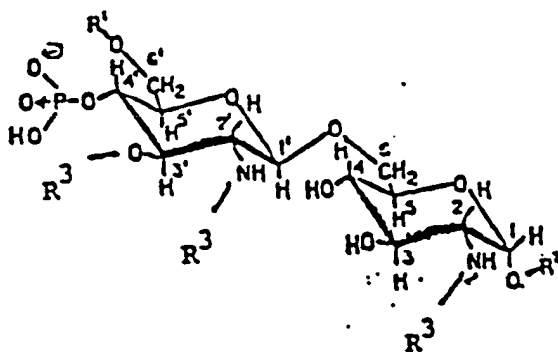
12. The method of Claim 10 or 11 wherein the inert, organic is a mixture of chloroform and methanol.

13. The method of Claim 10 which is effected in the presence of a phase transfer catalyst.

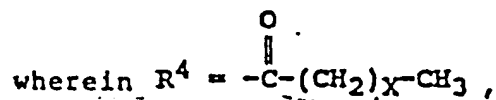
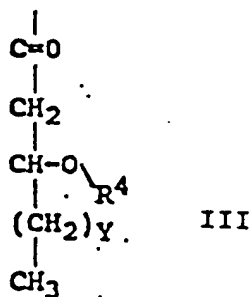
14. The method of Claim 13 wherein the phase transfer catalyst is tetrabutyl ammonium bromide.

15. A lipopolysaccharide from which the β -hydroxymyristic acyl group has been removed from position 3.

16. A biologically pure lipopolysaccharide compound of the formula:



wherein R^1 is selected from the group consisting of hydrogen and the core component of enterobacterial lipopolysaccharide, with the O-antigen present, R^2 is selected from the groups H and PO_3H_2 , and R^3 is selected from the group consisting of H, β -hydroxymyristoyl, and a 3-acyloxyacyl residue having the formula:



and wherein X and Y have a value of from 0 up to about 20.

17. The compound of Claim 16 wherein R^1 and R^2 are hydrogen.
18. The compound of Claim 16 wherein R^1 is hydrogen and R^2 is PO_3H .
19. The compound of Claim 16 wherein R^1 is hydrogen and R^2 is PO_3H_2 .
20. The compound of Claim 16 wherein R^1 and R^2 are hydrogen, and R^3 is the residue of Formula III.
21. The compound of Claim 20 wherein X has a value of 10, 12 or 14 and Y is 10.
22. A pharmaceutical composition comprising a substantially pure, modified lipopolysaccharide, having no β -hydroxymyristic acyl residue that is ester-linked to the reducing-end glucosamine at p sition 3, and a pharmaceutically acceptable carrier.

23. The pharmaceutical composition of Claim 22 wherein the lipopolysaccharide is enterobacterial lipopolysaccharide.

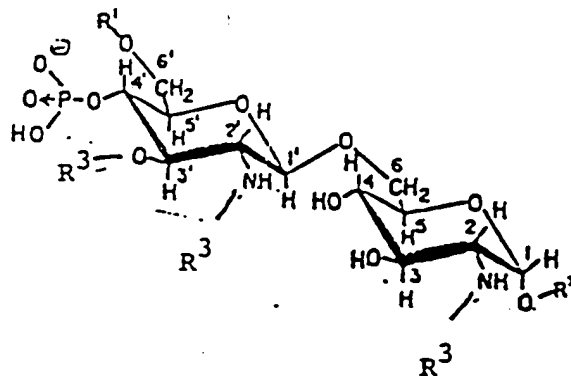
24. The pharmaceutical composition of Claim 22 wherein the lipopolysaccharide is monophosphoryl lipid A.

25. The pharmaceutical composition of Claim 22 wherein the lipopolysaccharide is diphosphoryl lipid A.

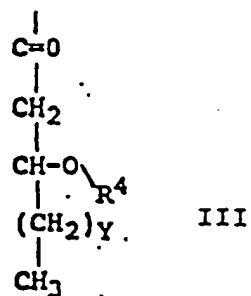
26. The composition of Claims 22-25 which possesses antigenic properties.

27. The composition of Claims 22-25 which possesses immunostimulating properties.

28. A biologically pure lipopolysaccharide compound of the formula



wherein R¹ is selected from the group consisting of hydrogen and the core component of enterobacterial lipopolysaccharide, without the O-antigen present, R² is selected from the groups H and PO₃H₂, and R³ is selected from the group consisting of H, β-hydroxymyristoyl, and a 3-acyl xyacyl residue having the formula:



wherein $\text{R}^4 = -\overset{\text{O}}{\parallel}{\text{C}}-(\text{CH}_2)_X-\text{CH}_3$,

and wherein X and Y have a value of from 0 up to about 20.